LIGHT HIGGS PRODUCTION AT THE COMPTON COLLIDER*

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We have studied the production of a light Higgs boson with a mass of 120 GeV in photon-photon collisions at a Compton collider. The event generator for the backgrounds to a Higgs signal due to $\overline{\mathrm{b}}\mathrm{b}$ and $\overline{\mathrm{c}}\mathrm{c}$ heavy quark pair production in polarized $\gamma\gamma$ collisions is based on a complete next-to-leading order (NLO) perturbative QCD calculation. For $J_z = 0$ the large double-logarithmic corrections up to four loops are also included. It is shown that the two-photon width of the Higgs boson can be measured with high statistical accuracy of about 2% for integrated $\gamma\gamma$ luminosity in the hard part of the spectrum of 40 fb^{-1}. As a result the total Higgs boson width can be calculated in a model independent way to an accuracy of about 14%.

1 Introduction

The experimental discovery of the Higgs boson is crucial for the understanding of the mechanism of electroweak symmetry breaking. The search for Higgs particles is one of the main goals for LEP2 and Tevatron and will be one of the major motivations for the future Large Hadron Collider (LHC) and Linear $\mathrm{e}^+\mathrm{e}^-$ Collider (LC). Once the Higgs boson is discovered, it will be of primary importance to determine its tree-level and one-loop induced couplings, spin, parity, CP-nature, and its total width in a model independent way. In this respect, the $\gamma\gamma$ Compton Collider [1] option of LC offers a unique possibility to produce the Higgs boson as an s-channel resonance decaying into $\overline{\mathrm{b}}\mathrm{b}$, WW* or ZZ:

$$\gamma\gamma \to \mathrm{h}^0 \to \overline{\mathrm{b}}\mathrm{b} \qquad (\mathrm{WW}^*, \mathrm{ZZ})$$

and thereby to measure the two-photon Higgs width. This partial width is of special interest, since it first appears at the one-loop level so that all heavy charged particles which obtain their masses from electroweak symmetry breaking contribute to the loop. Moreover, the contributions of very heavy particles do not decouple. In addition, combined measurements of $\Gamma(\mathrm{h} \to \gamma\gamma)$ and $\mathrm{BR}(\mathrm{h} \to \gamma\gamma)$ at the LC provide a model independent measurement of the total Higgs width [7].

The lower bound on m_{h} from direct searches at LEP is 95.2 GeV at 95 $C.L.$ [3]. Recent global analysis of precision electroweak data [2] suggests that the Higgs boson is light $m_{\mathrm{h}} = 92^{+78}_{-45}$ GeV. This fact is in a remarkable agreement with the well known upper bound of ~ 130 GeV for the lightest Higgs boson mass in the minimal version of supersymmetric theories, the Minimal Supersymmetric Standard Model (MSSM) [4]. For this case of a light Higgs boson the results of the Monte Carlo simulations of the Higgs production in $\gamma\gamma$ collisions with final decay to $\overline{\mathrm{b}}\mathrm{b}$ quark pairs will be presented here. Taking into account that the current upper bound

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on the Higgs mass from radiative corrections is $m_{\rm h} < 245$ GeV at 95% $C.L.$ [2], one can still hope to measure the two-photon Higgs width at the 300-500 GeV LC for heavier Higgs masses by studying its production in $\gamma\gamma$ collisions and final decays into WW^* [5] or ZZ [6] states.

The accuracy of the $\Gamma(\mathrm{h} \to \gamma\gamma)$ measurements to be reached can be inferred from the results of the studies of the coupling of the lightest SUSY Higgs boson to two photons in the decoupling regime [8]. It was shown that in the decoupling limit, where all other Higgs bosons are very heavy and no supersymmetric particle has been discovered at LHC or LC, chargino and top squark loops can generate a sizable difference between the standard and the SUSY two-photon Higgs couplings. Typical deviations are at the few percent level. Top squarks heavier than 250 GeV can induce deviations even larger than $\sim 10\%$ if their couplings to the Higgs boson are large.

2 Signal and Background

The cross-section of the resonant Higgs production at $\gamma\gamma$ Collider is proportional to the product

$$\sigma(\gamma\gamma \to \mathrm{h}^0 \to X) = z\frac{dL_{\gamma\gamma}}{dz}\frac{4\pi^2}{M^3_{h^0}}\Gamma(\mathrm{h}^0 \to \gamma\gamma)\cdot \mathrm{BR}(\mathrm{h}^0 \to \mathrm{X})(1+\lambda_1\lambda_2). \qquad (1)$$

Here the effective photon-photon luminosity $L_{\gamma\gamma}$ is introduced (see the next section). $\lambda_{1,2}$ are mean high energy photon helicities.

Standard Model (SM) Higgs branching ratios and Higgs total width are calculated with the help of the program HDECAY [10]. The program includes the full massive NLO corrections for $h \to \overline{\mathrm{q}}\mathrm{q}$ decays close to the thresholds as well as the massless $\mathcal{O}(\alpha_s^3)$ corrections far above the thresholds. For the Higgs signal only two-particle final states are generated, so that Parton Shower (PS) algorithm of JETSET have been used to simulate three and higher particle final states.

The main background to the h^0 production is the continuum production of $\overline{\mathrm{b}}\mathrm{b}$ and $\overline{\mathrm{c}}\mathrm{c}$ pairs. In this respect, the availability of high degree of photon beams circular polarization is crucial, since for the equal photon helicities ($\pm\pm$) that produce spin-zero resonant states, the $\gamma\gamma \to \overline{\mathrm{q}}\mathrm{q}$ QED Born cross-section is suppressed by the factor m_q^2/s [11]:

$$\frac{d\sigma^{\mathrm{Born}}(J_z=0)}{dt} = \frac{12\pi\alpha^2 Q_q^4}{s^2}\frac{m_q^2 s^2(s-2m_q^2)}{t_1^2 u_1^2}, \qquad (2)$$

and

$$\frac{d\sigma^{\mathrm{Born}}(J_z=\pm 2)}{dt} = \frac{12\pi\alpha^2 Q_q^4}{s^2}\frac{(t_1u_1 - m_q^2 s)(u_1^2+t_1^2+2m_q^2 s)}{t_1^2 u_1^2}. \qquad (3)$$

Here m_q is the quark mass, Q_q its charge, and $t_1 = t - m_q^2$, $u_1 = u - m_q^2$.

Virtual one-loop QCD corrections for $J_z = 0$ were found to be especially large due to the double-logarithmic enhancement factor, so that the corrections are comparable or even larger than the Born contribution for the two-jet final topologies [12].

For small values of the cutoff $y_{\rm cut}$ separating two and three-jet events two-jet cross-section, calculated to order α_s, becomes even negative in the central region. Recently leading double-logarithmic QCD corrections for $J_z = 0$ were resummed to all orders [13]. The account of non-Sudakov form factor to higher orders makes the cross-section well defined and positive definite in all regions of the phase space.

The simulation program includes exact one-loop QCD corrections to heavy quark production in $\gamma\gamma$ collisions [12] and non-Sudakov form factor in the double-logarithmic approximation through four loops [13]:

$$\frac{\sigma_{\rm virt}^{\rm DL}}{\sigma_{\rm Born}} \sim 1 + 6\mathcal{F} + \frac{1}{6}\left(56 + 2\frac{C_A}{C_F}\right)\mathcal{F}^2 + \frac{1}{90}\left(94 + 90\frac{C_A}{C_F} + 2\frac{C_A^2}{C_F^2}\right)\mathcal{F}^3$$
$$+\frac{1}{2520}\left(418 + 140\frac{C_A}{C_F} + 238\frac{C_A^2}{C_F^2} + 3\frac{C_A^3}{C_F^3}\right)\mathcal{F}^4 \qquad (4)$$

where $\mathcal{F} = -C_F\frac{\alpha_s}{4\pi}\log^2\frac{m_q^2}{s}$ is the one-loop hard form factor. Since it is a non-trivial task to write down an event generator including both NLO corrections and PS algorithm, we do not use any PS for background $\overline{\rm b}$b and $\overline{\rm c}$c production. So the experimental value of $y_{\rm cut}$ parameter should not be taken very small, otherwise the account of resummed Sudakov corrections is needed. Two parton ($\overline{\rm b}$b, $\overline{\rm c}$c, and $\overline{\rm b}$bg, $\overline{\rm c}$cg with $y_{\rm cut} < 0.01$) and three parton ($\overline{\rm b}$bg, $\overline{\rm c}$cg with $y_{\rm cut} > 0.01$) final states were generated separately and JETSET [15] string fragmentation algorithm was used afterwards. The event generator itself both for the Higgs signal and heavy quark background is implemented using the programs BASES/SPRING [14].

3 $\gamma\gamma$ Luminosity

The original polarized photon energy spectra [9] were used. 100% laser and 85% electron beam polarizations were assumed with $2\lambda_e^{1,2}\lambda_\gamma^{1,2} = -0.85$. The Parameter $x = \frac{4E_e\omega_0}{m_e^2}$ was taken to be equal to 4.8. Assuming that the Higgs boson will already be discovered at LHC and/or LC and its mass will be also measured, we tune the ee collision energy to be equal to 152 GeV so that the Higgs mass of 120 GeV is just at the peak of the photon-photon luminosity spectrum $z\frac{dL_{\gamma\gamma}}{dz}$, $z = 0.8$, where

$$z = \frac{W_{\gamma\gamma}}{2E_e}, \quad z_{\rm max} = \frac{x}{x+1} = 0.83$$

We assume an integrated $\gamma\gamma$ luminosity of $L_{\gamma\gamma}(0 < z < z_{\rm max}) = 150$ fb^{-1}. Realistic simulations of the $\gamma\gamma$ luminosity [1] taking into account beamstrahlung, coherent pair creation and interaction between charged particles show that idealized spectra [9] will be strongly distorted in the low energy part of the spectrum. However, in the hard part of the spectrum which is relevant for our simulation, the spectra [9] represent a very good approximation [1]. The luminosity in the hard part of the spectrum is $L_{\gamma\gamma}(0.65 < z < z_{\rm max}) = 43$ fb^{-1} which corresponds to a luminosity of the ee collisions of $L_{\rm ee} \approx 200$ fb^{-1}.

4 Cross-Sections

$m_{h^0} = 120$ GeV	σ [pb] $\lvert\cos\theta\rvert) < 0.7$	$N_{\rm ev}$	$N_{\rm ev}$ with b-tag
$\gamma\gamma \to h^0 \to \overline{\rm b}{\rm b}$	0.105	15700	11000
$\gamma\gamma \to \overline{\rm b}{\rm b}({\rm g}),\ J_z = 0$	0.0294		
$J_z = 2$	0.0654		
total	0.0947	14200	9940
$\gamma\gamma \to \overline{\rm c}{\rm c}({\rm g}),\ J_z = 0$	0.425		
$J_z = 2$	1.03		
total	1.45	217000	7610
$\gamma g \to \overline{\rm b}{\rm b}$	$7.45\ 10^{-4}$	112	78
$\gamma g \to \overline{\rm c}{\rm c}$	$2.96\ 10^{-3}$	445	16

Table 1: Cross-sections and event rates for the Higgs signal and backgrounds from direct and resolved heavy quark production in $\gamma\gamma$ collisions. The $\gamma \to \overline{\rm b}{\rm b}({\rm g}), \overline{\rm c}{\rm c}({\rm g})$ background was simulated for $\gamma\gamma$ invariant masses larger than 100 GeV.

In Table 1, we give the cross-sections and event rates for the Higgs signal and backgrounds calculated without detector simulation. For $\overline{\rm b}{\rm b}({\rm g})$, $\overline{\rm c}{\rm c}({\rm g})$ backgrounds the $J_z = 0$ and $J_z = 2$ contributions are shown separately. b-tagging efficiencies of 70 % for $\overline{\rm b}{\rm b}$ events and 3.5 % for $\overline{\rm c}{\rm c}$ events were assumed. Both quark jets were assumed to satisfy the $\lvert\cos\theta\rvert < 0.7$ cut. The resolved photon contribution to the $\overline{\rm b}{\rm b}$ background is negligible. It was therefore not included in the subsequent detector simulation analysis. Assuming

$$\frac{\Delta\Gamma({\rm h} \to \gamma\gamma)}{\Gamma({\rm h} \to \gamma\gamma)} = \frac{\sqrt{N_{\rm obs}}}{N_{\rm obs} - N_{\rm BG}},$$

where $N_{\rm obs}$ is the sum of the signal and background events and $N_{\rm BG}$ the number of background events, the first estimate of the statistical error of two-photon Higgs partial width measurement is 1.5% for $m_h = 120$ GeV. For heavier Higgs masses we get the statistical error of 1.9% (6.1%) for $m_h = 140$ GeV ($m_h = 160$ GeV), respectively.

5 Results of the Monte Carlo Simulation

The Monte Carlo simulation of the fragmentation is done with JETSET [15]. Signal and background are studied using the fast detector simulation program SIMDET [16] for a typical TESLA detector. The Higgs mass was assumed to be 120 GeV. Jets were reconstructed using the Durham algorithm with $y_{\rm cut} = 0.02$. b tagging is not simulated and b tagging efficiencies of 70 % for $\overline{\rm b}{\rm b}$ events and 3.5 % for $\overline{\rm c}{\rm c}$ events were used instead [17]. These efficiencies are based on double-tagging of b jets to suppress $\overline{\rm c}{\rm c}$ events by a factor of 20 which is large enough to overcome the enhancement factor of 16 due to the larger c quark charge. The multiplicities for

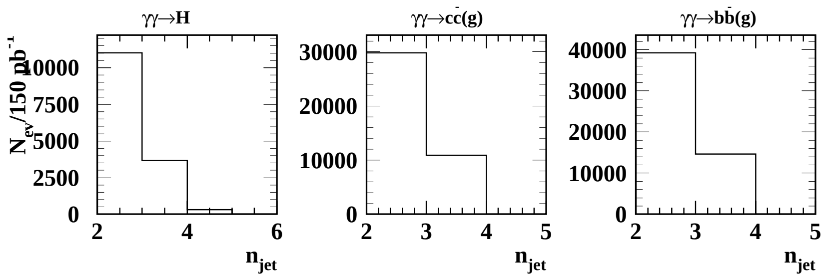

Figure 1: Jet multiplicities for two- and three-parton events.

the Higgs signal and heavy quark background are shown in Fig. 5. The following cuts were used to suppress heavy quark background:
1.) To suppress the background at the peak, exactly two jets must be found in the event ($n_{\mathrm{jet}} = 2$).
2.) Events where quark jets were scattered at a small angle were rejected by requiring for the thrust angle $|\cos\theta_{\mathrm{T}}| < 0.7$ (see Fig. 2).

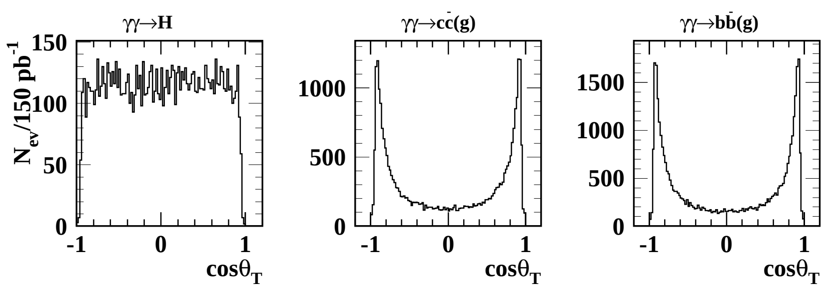

Figure 2: $\cos\theta_T$ distributions for two- and three-parton events with $n_{\mathrm{jet}} = 2$.

3.) Since the Higgs boson is produced at the peak of photon-photon luminosity almost at rest the cut on longitudinal momentum component of the event divided by the ee centre-of-mass energy, $|p_{\mathrm{z}}|/\sqrt{s}_{\mathrm{ee}} < 0.1$, further reduces the background.
4.) Most background events are produced at the lower energy tail of the photon-photon luminosity distribution. A cut on the total visible energy, $E_{\mathrm{vis}}/\sqrt{s}_{\mathrm{ee}} > 0.6$, eliminates most soft background events.

After these cuts a signal efficiency

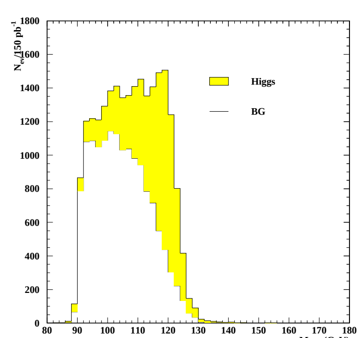

Figure 3: Mass distributions for Higgs signal and heavy quark background.

of about 50% is achieved. The invariant mass distributions for the combined $\overline{\mathrm{b}}\mathrm{b}(\mathrm{g})$ and $\overline{\mathrm{c}}\mathrm{c}(\mathrm{g})$ background, and for the Higgs signal are shown in Fig. 5.

After these cuts 8104 signal events and 14690 background events remain yielding a relative error

$$\frac{\Delta[\Gamma(\mathrm{h}\to\gamma\gamma)\mathrm{BR}(\mathrm{h}\to\overline{\mathrm{b}}\mathrm{b})]}{[\Gamma(\mathrm{h}\to\gamma\gamma)\mathrm{BR}(\mathrm{h}\to\overline{\mathrm{b}}\mathrm{b})]}\approx 2\%.$$

Since resummation of Sudakov logarithms was not done for the heavy quark background a question may arise on the effect of these corrections on the errors on $\Gamma(\mathrm{h}\to\gamma\gamma)$. To estimate this effect the analysis was repeated without cut on n_{jet}. In this case no Sudakov logarithms are present. This increases the signal by about 36% and the background by about 50% in Fig. 5 which yields a comparable statistical error as with jet multiplicity cut. In comparison to the results presented in Table 1 taking into account of the detector simulation effects gives slightly lower accuracy. Taking this value and assuming, that at the e^+e^- linear collider one can measure the $h\to\overline{\mathrm{b}}\mathrm{b}$ and $h\to\gamma\gamma$ branching ratios with the accuracy of

$$\frac{\Delta\mathrm{BR}(\mathrm{h}\to\overline{\mathrm{b}}\mathrm{b})}{\mathrm{BR}(\mathrm{h}\to\overline{\mathrm{b}}\mathrm{b})}=5\%\quad\text{and}\quad\frac{\Delta\mathrm{BR}(\mathrm{h}\to\gamma\gamma)}{\mathrm{BR}(\mathrm{h}\to\gamma\gamma)}=13\%$$

one can estimate, that the total width of the Higgs boson can be calculated

$$\Gamma_{\mathrm{h}}=\frac{[\Gamma(\mathrm{h}\to\gamma\gamma)\mathrm{BR}(\mathrm{h}\to\overline{\mathrm{b}}\mathrm{b})]}{[\mathrm{BR}(\mathrm{h}\to\gamma\gamma)][\mathrm{BR}(\mathrm{h}\to\overline{\mathrm{b}}\mathrm{b})]}$$

to the accuracy of about 14%. This error is dominated by the expected error on $\mathrm{BR}(\mathrm{h}\to\gamma\gamma)$.

The influence of the values of the b tag efficiencies for $\overline{\mathrm{b}}\mathrm{b}$ and $\overline{\mathrm{c}}\mathrm{c}$ events on the accuracy of two-photon Higgs width was also studied. b and c tag efficiencies were taken from a parametrisation by M. Battaglia [17]. In the region of b tag efficiencies from 50% to 90% the relative error on $\Gamma(\mathrm{h}\to\gamma\gamma)\mathrm{BR}(\mathrm{h}\to\overline{\mathrm{b}}\mathrm{b})$ is quite stable and has a value about 2%.

6 Conclusions

Our preliminary results show that the two-photon width of the Higgs boson can be measured at the photon-photon collider with high statistical accuracy of about 2%. At such an accuracy one can discriminate between the SM Higgs particle and the lightest scalar Higgs boson of the MSSM in the decoupling limit, where all other Higgs bosons are very heavy and no supersymmetric particle has been discovered at the e^+e^- LC. Due to the large charm production cross-section in $\gamma\gamma$ collisions, excellent b tagging is required. Our results are consistent with the earlier results [18], where higher order double logarithmic correction were not taken into account. To get more realistic $\Gamma(\mathrm{h}\to\gamma\gamma)$ error one still needs to understand the systematic errors. Since precise knowledge of the heavy quark background is essential for accurate measurements of the Higgs signal, it is worth mentioning, that one should

not necessarily rely on the theoretical predictions of $\overline{\text{b}}$b and $\overline{\text{c}}$c backgrounds. Since the light Higgs boson is expected to be very narrow, it will be possible by slightly changing the electron beam energy to completely eliminate the Higgs signal events and thereby just to measure the heavy quark background.

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